

W/Z + Jets Production at the Tevatron

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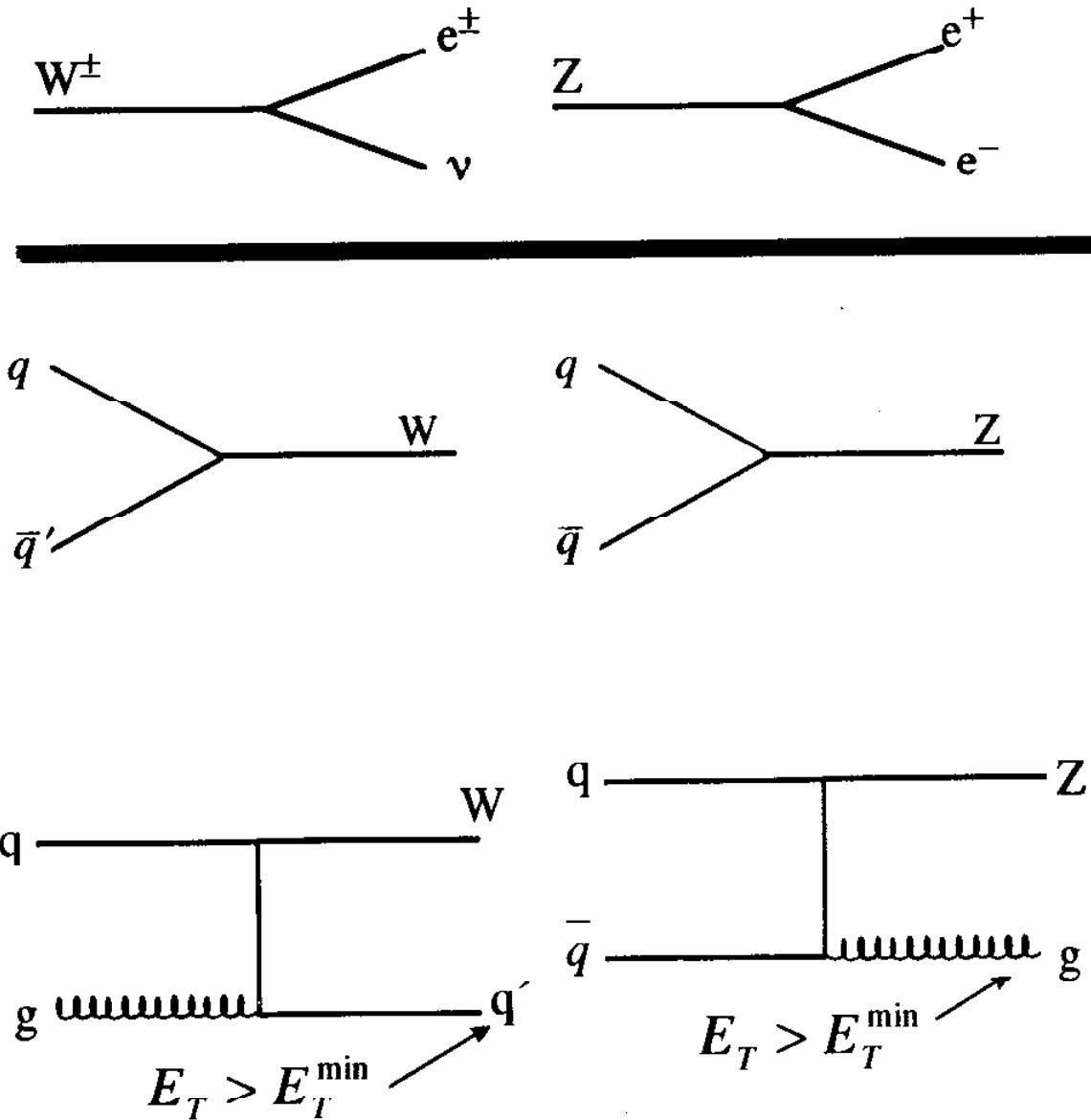
Northwestern University

for the DØ Collaboration

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W/Z + Jets



Overview

- * Properties of jets in W/Z + $\geq N$ Jets events from CDF
 - * W + $\geq N$ Jets cross sections measured for N = 1 to 4
 - * Comparison of jet E_T , M_{jj} , ΔR_{jj} , distributions to QCD predictions
- * Measurement of the ratio $(W+1\text{ Jet})/(W+0\text{ Jets})$ at DØ
- * Color Coherence Measurements in W+Jets events at DØ
- * All analyses use $W^\pm \rightarrow e^\pm \nu$ events

Parameters by Experiment

Parameter	CDF	DØ
electron E_T	20 GeV	25 GeV
missing E_T	30 GeV	25 GeV
Jet cone	0.4	0.7
Jet E_T	15 GeV	20 GeV (R^{10}) 10 GeV (CC)
Monte Carlo	LO (VECBOS) + gluon shower	NLO (Dyrad) (Pythia)

CDF Event Sample

- * 108 pb^{-1} at $\sqrt{s} = 1.8 \text{ TeV}$
- * $W \rightarrow e\nu$ (51,431 events)
 - * Tight, central electron ($E_T > 20 \text{ GeV}$, $|\eta_d| < 1.1$)
 - * missing $E_T > 30 \text{ GeV}$
- * $Z \rightarrow ee$ (6708 events)
 - * One tightly selected central electron
 - * One loosely selected electron
 - * $|M_{ee} - M_Z| < 15 \text{ GeV}/c^2$

CDF Jet Selection

- * Cone algorithm ($R = 0.4$)
- * Corrected for
 - * calorimeter response
 - * out of cone losses
 - * underlying event
- * Selection
 - * $E_T > 15 \text{ GeV}$
 - * $|\eta_d| < 2.4$
 - * $R_{jj} > 1.3 * R = 0.52$
- * Backgrounds
 - * multiple interactions
(-3% to -10% correction)
 - * direct photons faking jets
(-1% to -3% correction)

Backgrounds and Efficiencies

- * $W^\pm \rightarrow e^\pm \nu$ Backgrounds
 - * QCD multijet background (2.9% to 27%)
 - * $W \rightarrow \tau\nu, Z \rightarrow \tau\tau, Z \rightarrow ee$ (3%)
 - * top, dibosons (0.1% to 17%)
- * $Z \rightarrow e^+e^-$ Backgrounds
 - * QCD multijet (<1% to <4 %)
 - * Drell-Yan (1.5%)
 - * diboson (negligible)
- * Overall detection efficiencies
 - * 20% for $W^\pm \rightarrow e^\pm \nu$
 - * 30% for $Z \rightarrow e^+e^-$

Measuring W+ $\geq N$ Jet Cross Sections

- * Measure

$$\sigma_n \cdot BR = \sigma(W + \geq n \text{ Jets}) \cdot BR(W \rightarrow e \nu)$$

- * for n = 1 to 4 via the ratio

$$\sigma_n \cdot BR = \sigma_0 \cdot BR \cdot \frac{(N_n - B_n) \cdot \epsilon_0}{(N_0 - B_0) \cdot \epsilon_n}$$

- * where:

- * N_n = number of W candidates with $\geq n$ jets
- * B_n = total background for $\geq n$ jets
- * ϵ_n = detection efficiency for $\geq n$ jets
- * σ_0 = CDF run previously published W cross section measurement,
 $2490 \pm 120 \text{ pb}$ *

*F. Abe *et al.*, PRL 76, 3070.

CDF W+ \geq N Jet Cross Sections

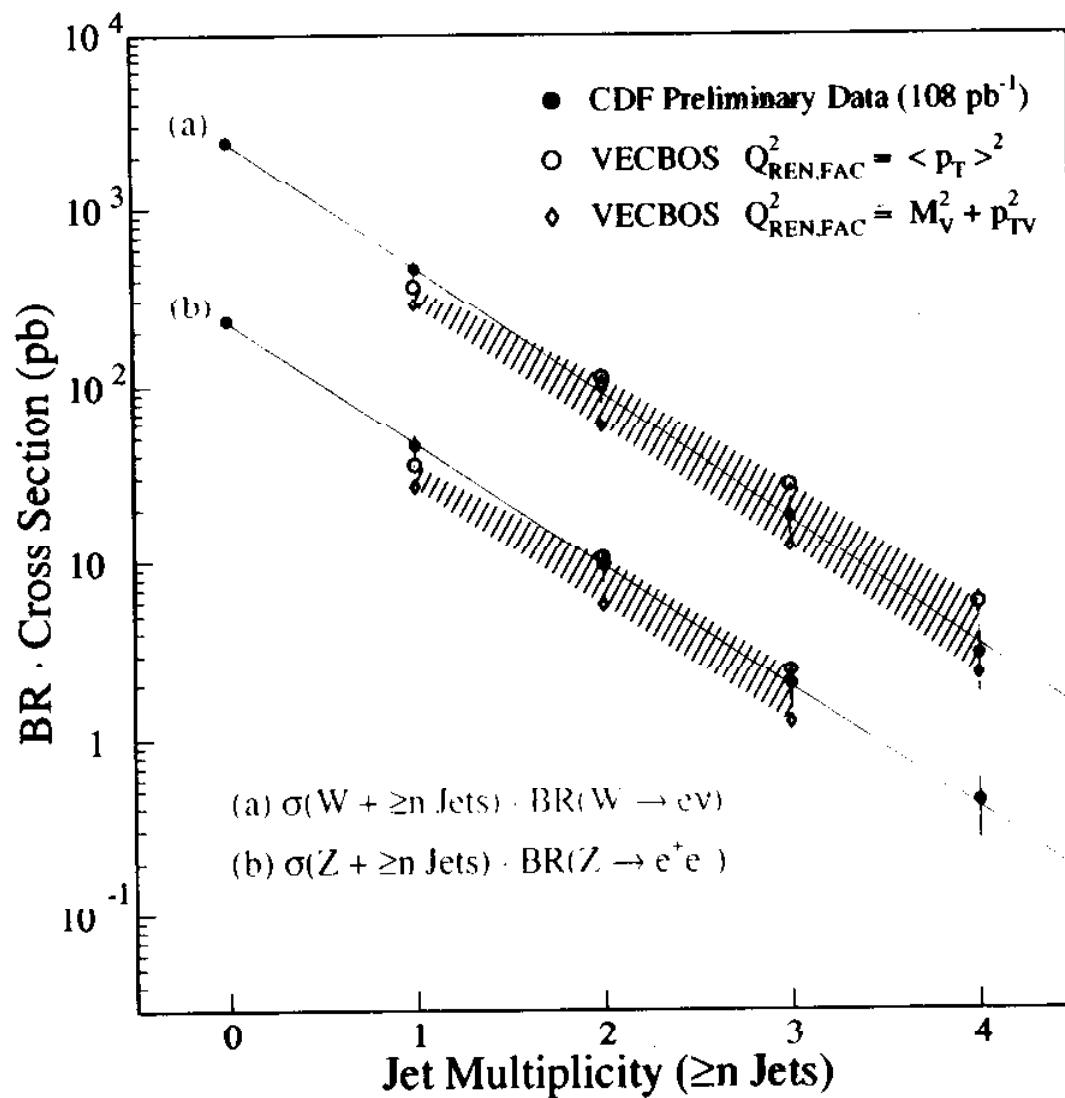
Preliminary:

N Jets	$\sigma \cdot BR$ (pb)
≥ 0	$\equiv 2490 \pm 120$
≥ 1	$471 + 5.4 \pm 57$
≥ 2	$101 \pm 2.4 \pm 19$
≥ 3	$18.4 \pm 1.1 \pm 5.2$
≥ 4	$3.1 \pm 0.6 \pm 1.3$

Leading Order Predictions

- * VECBOS Monte Carlo to calculate matrix elements
- * Use MRSA' and CTEQ3M parton distribution functions
- * Two renormalization scales
 - * $Q^2 = \langle p_T \rangle^2$ of partons
 - * $Q^2 = M^2 + p_T^2$
- * HERWIG gluon radiation and fragmentation
- * Full CDF detector simulation
- * Analysis cuts applied just as they are for data

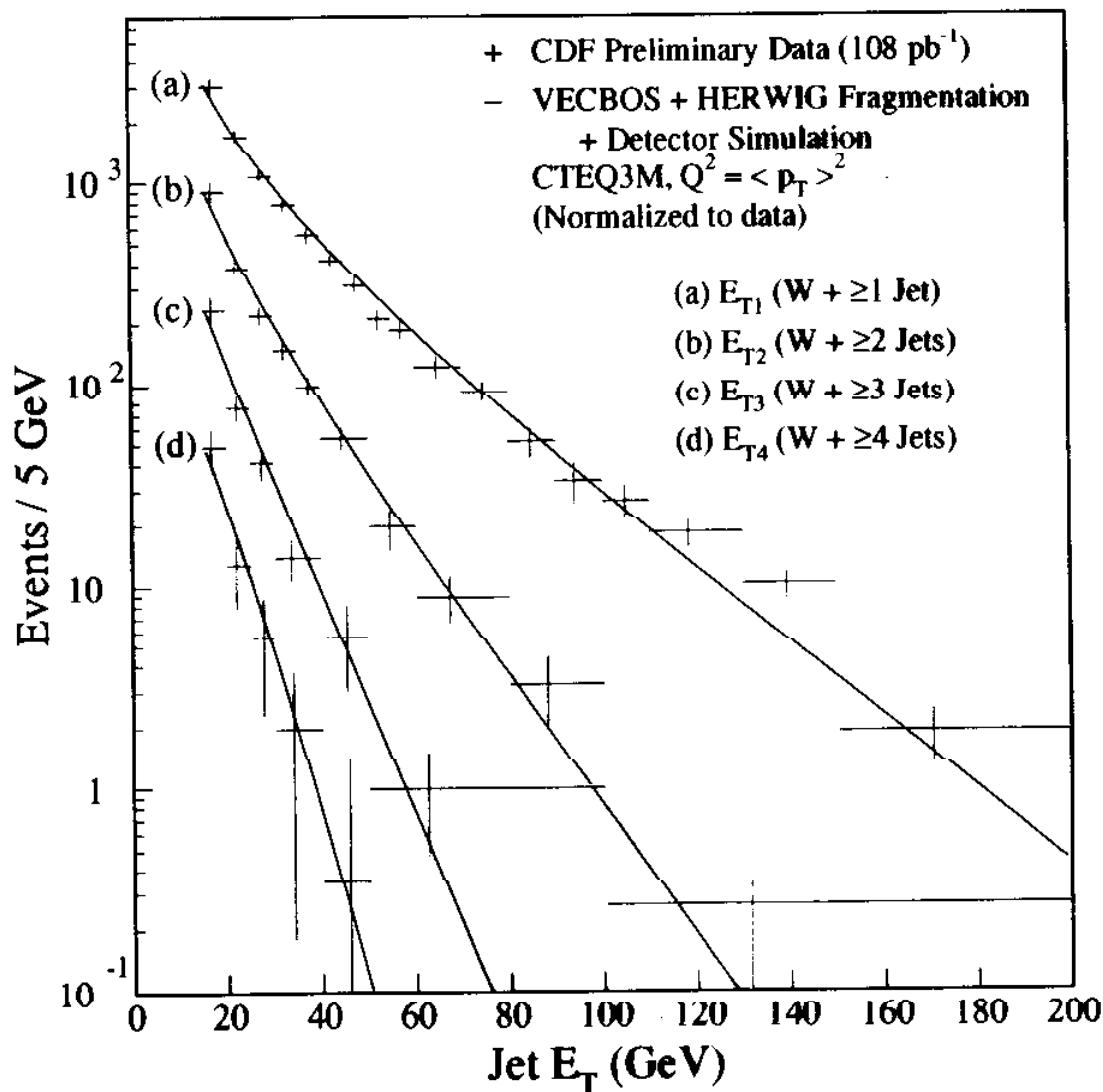
W/Z + $\geq n$ Jet Cross Sections



Z+ n jet cross sections from F. Abe *et al.*, PRL 77, 448.

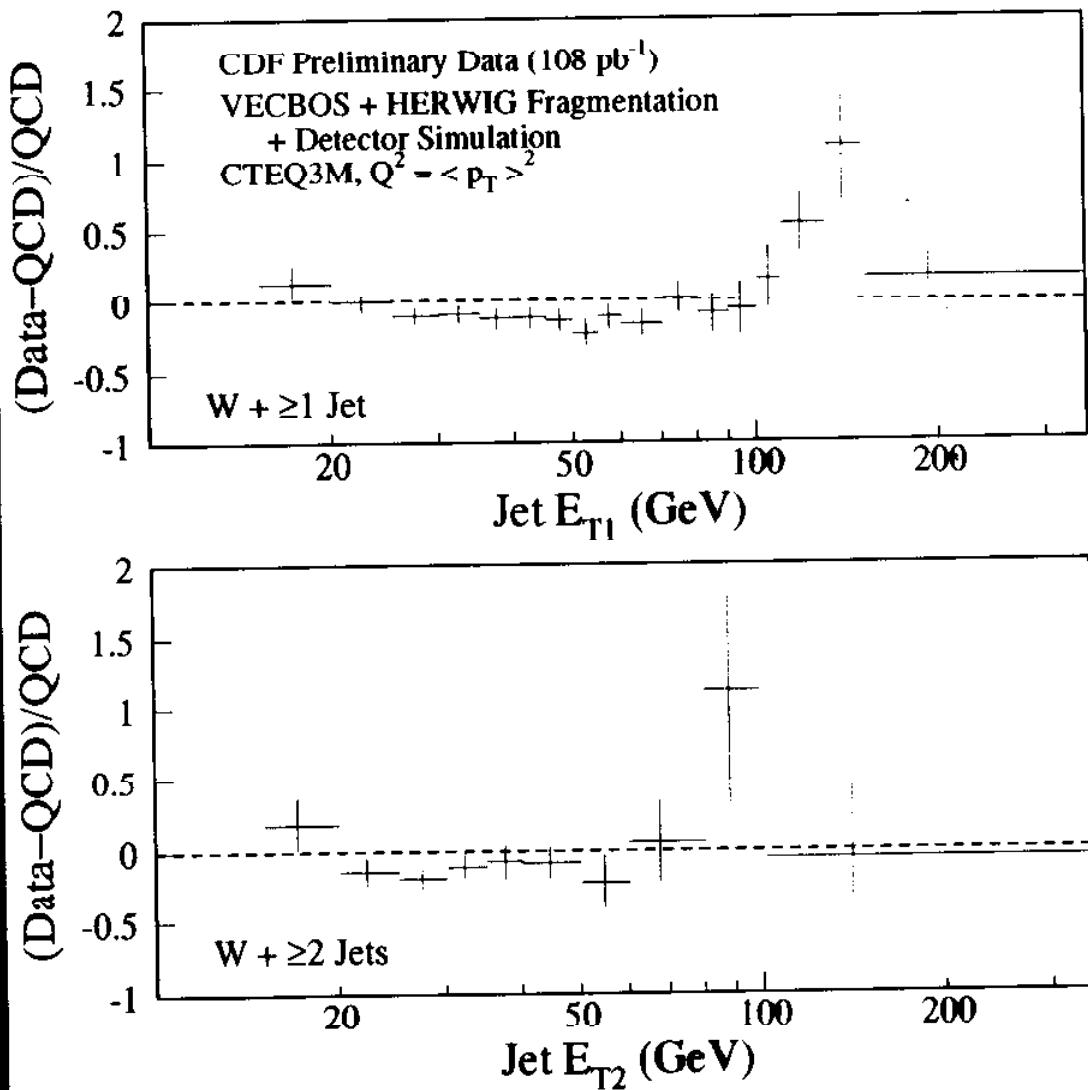
Jet E_T Distributions

* shape comparisons

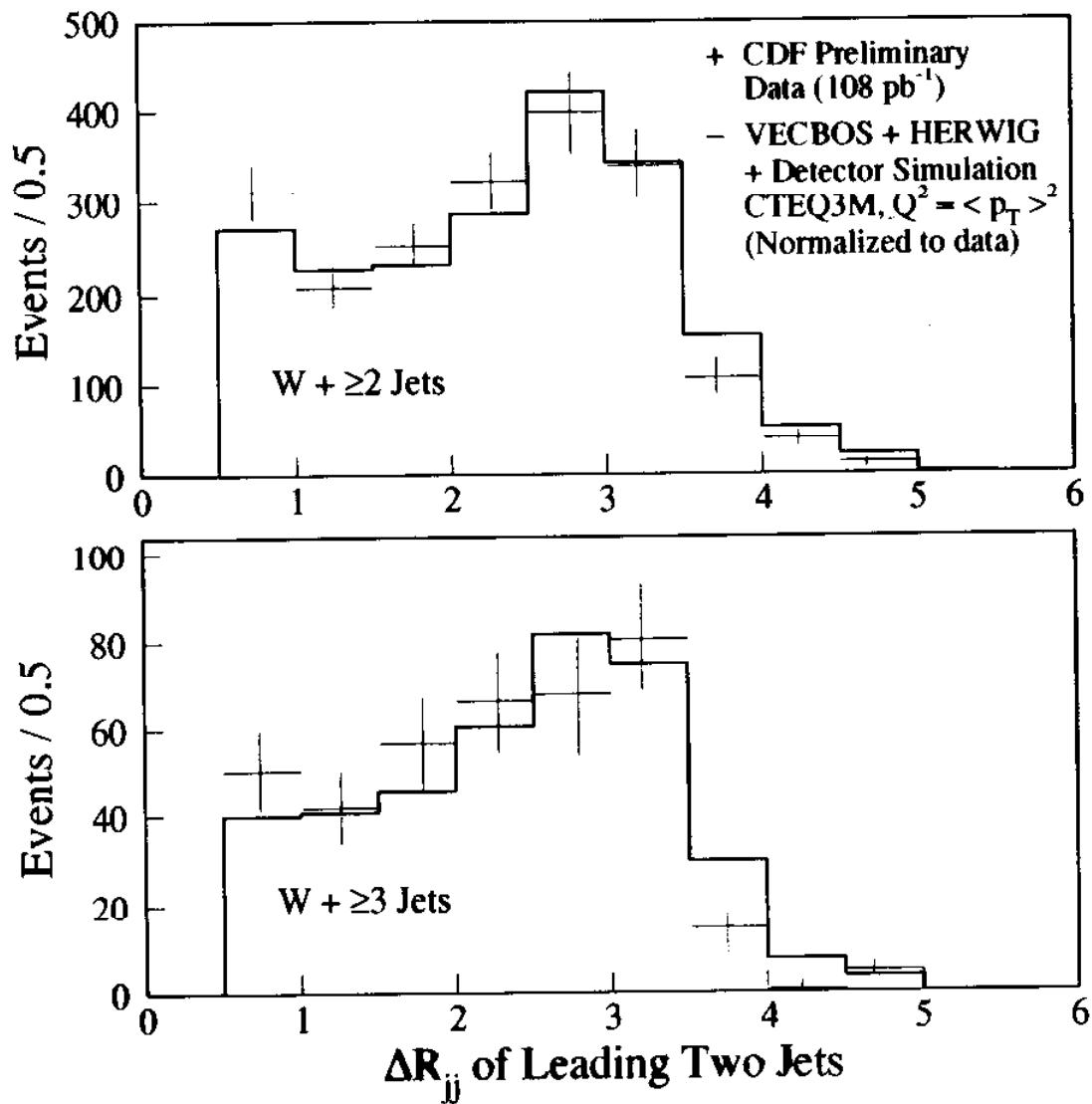


Error bars include statistical uncertainties and background subtraction systematics.

Jet E_T compared to Theory

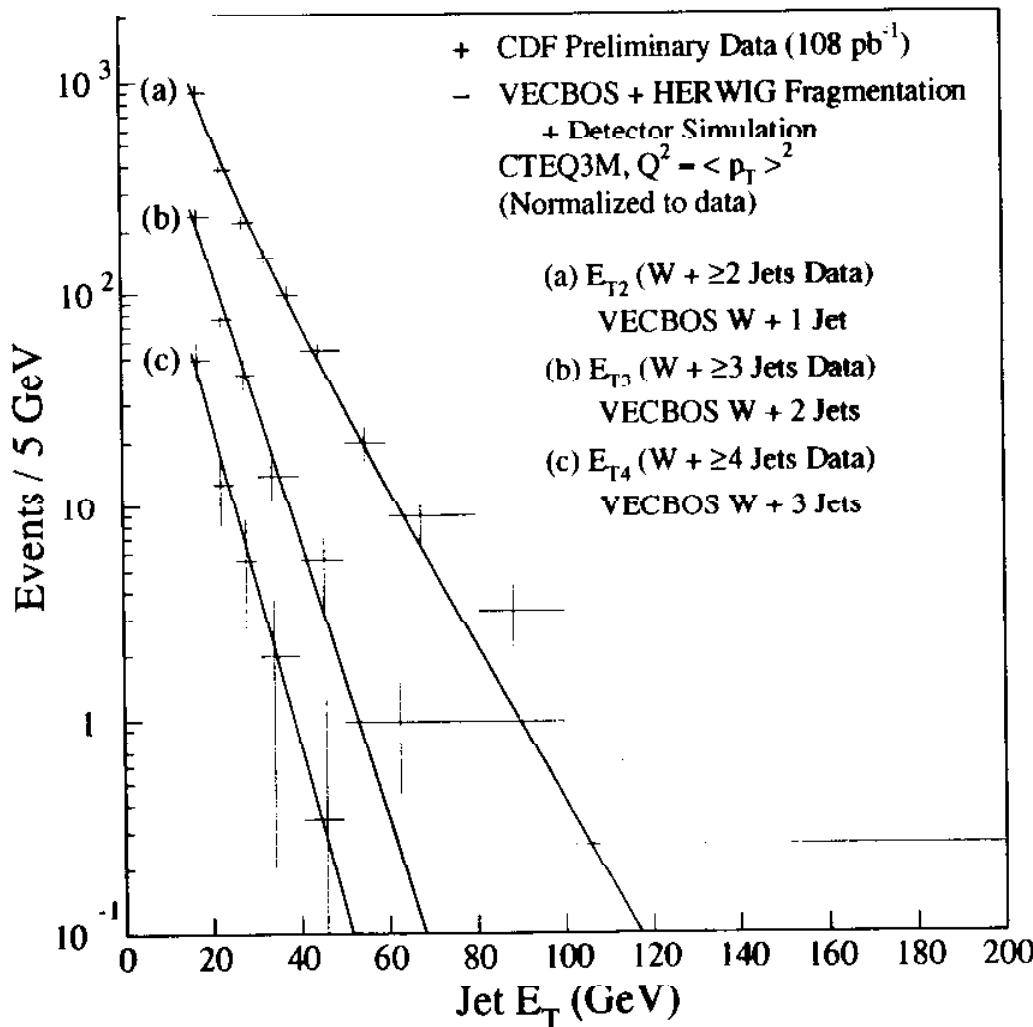


ΔR_{jj} Comparisons

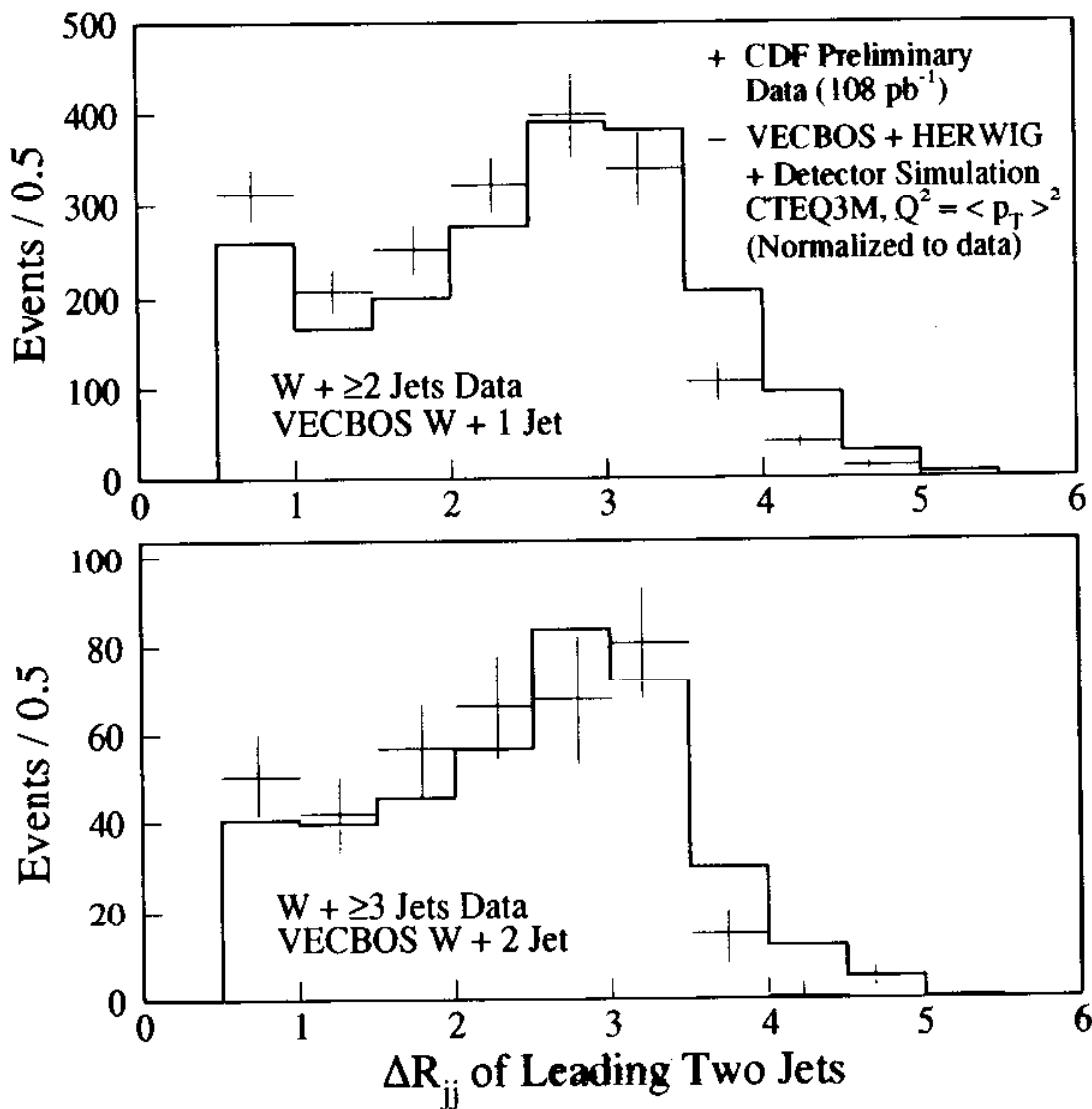


HERWIG “Feed-up” Tests

- * Compare $W + \geq N$ jets data to
 $W + \geq (N-1)$ Jets VECBOS
- * Use extra jets from HERWIG parton
shower model



HERWIG “Feed-up” and ΔR_{jj}



W/Z + N Jets

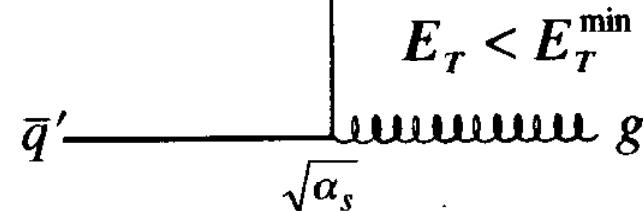
Conclusions

- * New W + $\geq N$ Jets cross sections measured at CDF.
- * Cross sections are 1.7 times larger than theory ($Q^2 = M_W^2 + p_{TW}^2$)
- * W and Z data exhibit similar jet distributions
- * Jet production observables (E_T , M_{jj} , ΔR_{jj}) are well produced by theory (up to a scale factor).
- * Herwig parton shower model produces jet E_T spectra which agree with data. Some disagreement of other jet variables.

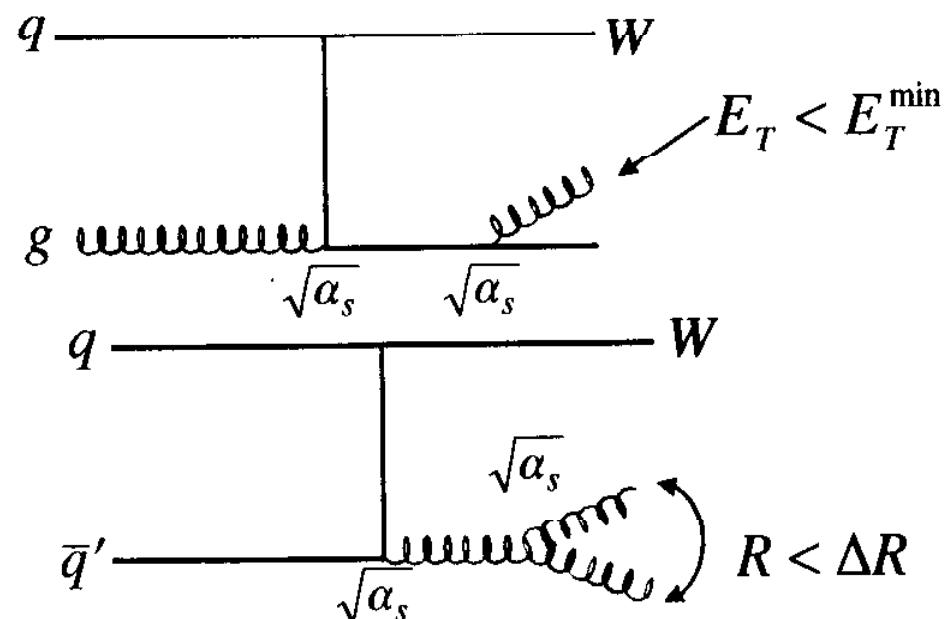
~~DØ~~: R^{10} and NLO



$W+0\text{ Jets:}$



$W+1\text{ Jet:}$



$$R^{10} = \frac{\sigma(W+1\text{Jet})}{\sigma(W+0\text{Jets})}$$

- * NLO calculations use the DYRAD Monte Carlo.
(Giele, Glover, Kosower, NPB403, 1993)

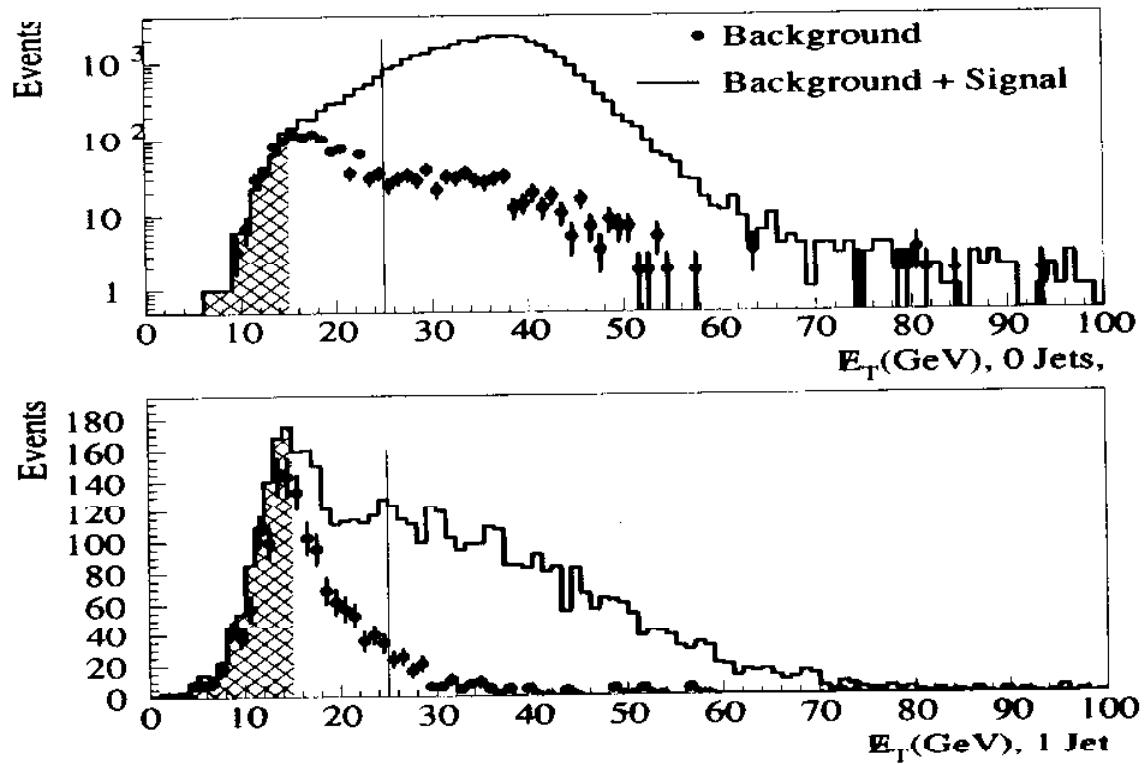
Data Selection

- * 76 pb-1 at $\sqrt{s} = 1800 \text{ GeV}$
- * electron $E_T > 25 \text{ GeV}$
- * electron must be central $|\eta| < 1.0$
- * electron must be isolated
- * missing $E_T > 25 \text{ GeV}$
- * jets reconstructed using a fixed cone algorithm with a radius of 0.7
- * study R^{10} versus E_T^{\min}
 - * exclusive multiplicities
- * event quality cuts
- * 36984 events total
 - * 33617 - zero jets ($E_T^{\min} = 25 \text{ GeV}$)
 - * 2829 - one jet ($E_T^{\min} = 25 \text{ GeV}$)

Background Subtraction

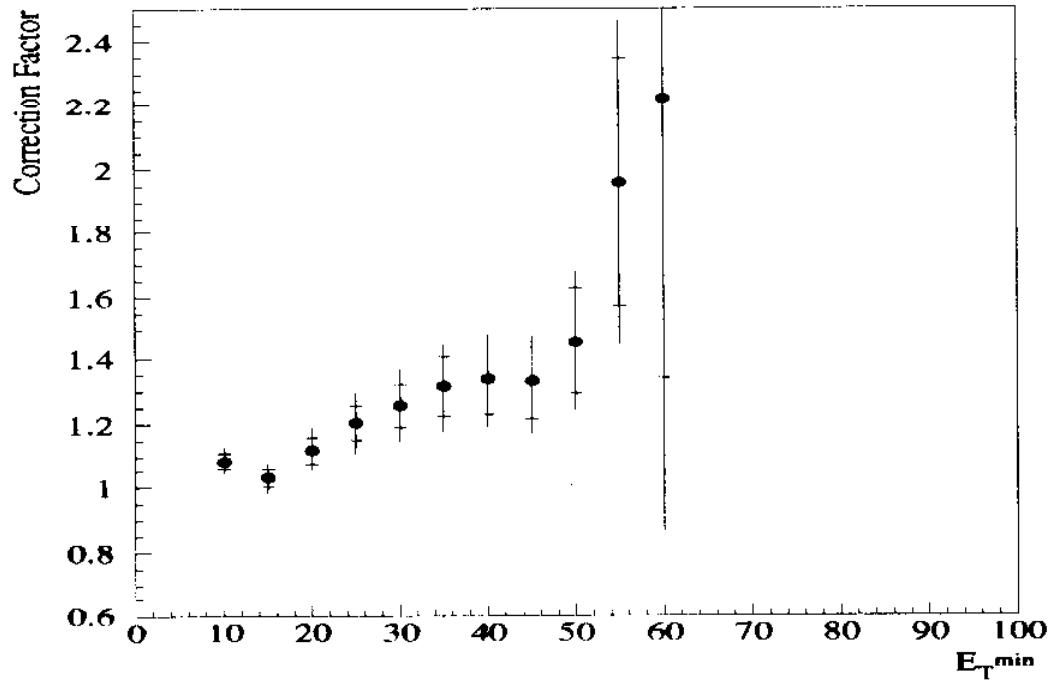
- * multijet and direct photon events
(1.5% to 20%)
- * other electroweak processes
(0.5% to 2%)
 - * $Z \rightarrow e^+e^-$
 - * $Z \rightarrow \tau^+\tau^-$

Multijet Background Subtraction

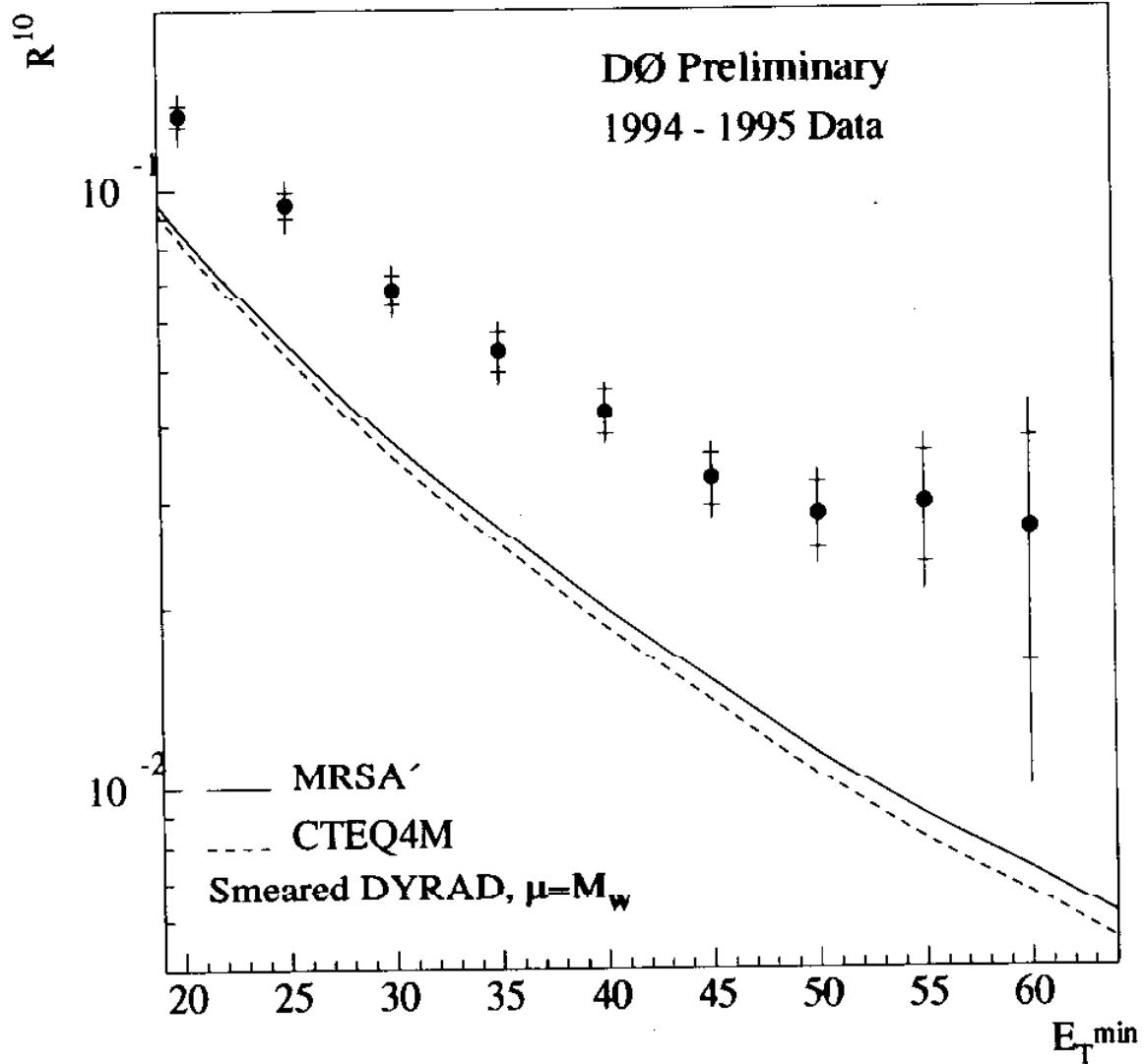


Data Corrections

- * Hadronic energy calibration
 - * $\pm 5\%$ error for $E_T^{\min}=25 \text{ GeV}$
- * Electromagnetic energy calibration
- * Electron efficiency correction
 - * $\pm 5\%$ error for $E_T^{\min}=25 \text{ GeV}$
 - * depends on jet multiplicity and jet E_T
 - * trigger and off-line cut efficiencies



R^{10} vs. E_T^{\min}

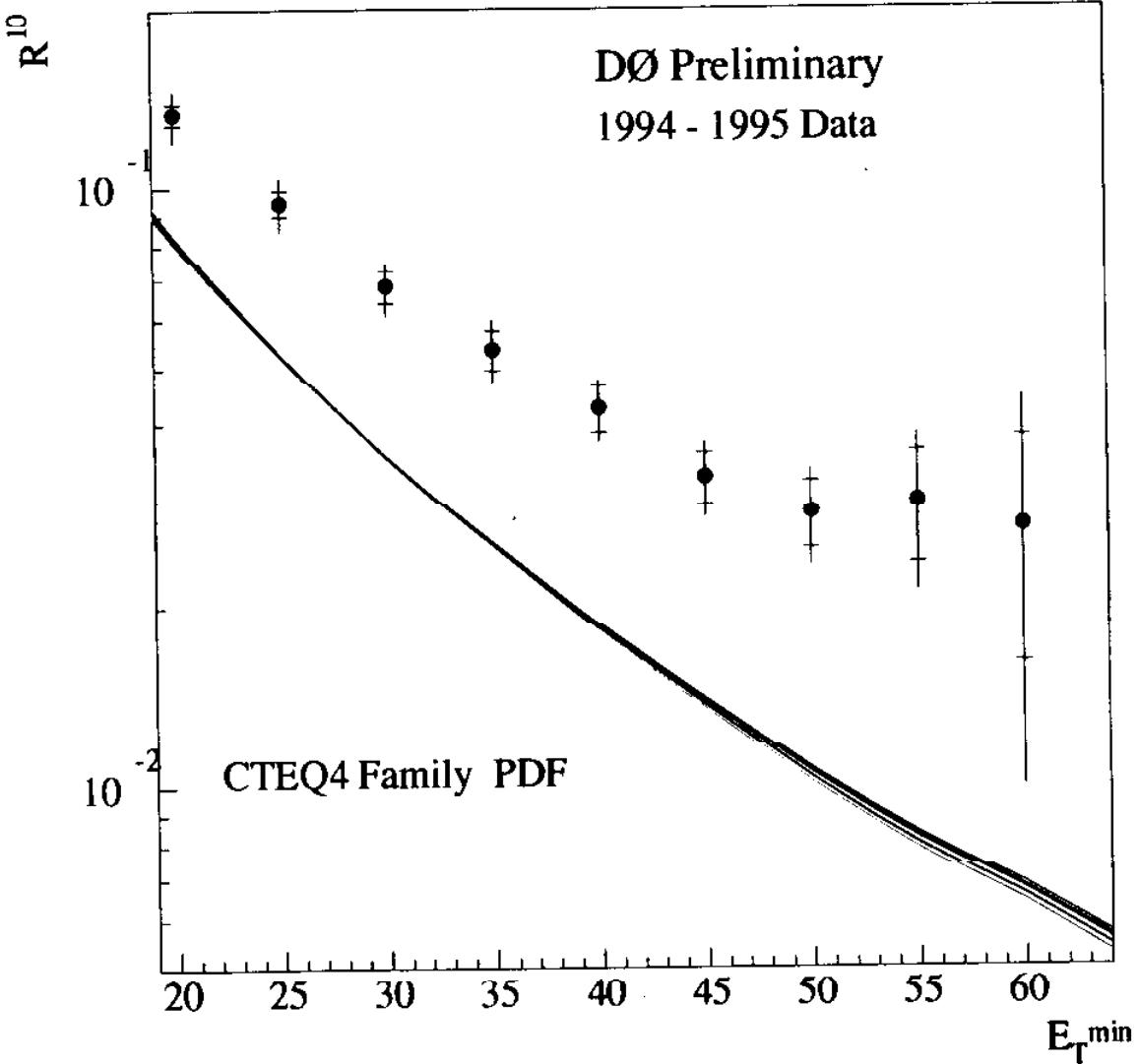


- * inner error is statistical only
- * outer error bar is statistical and systematic added in quadrature

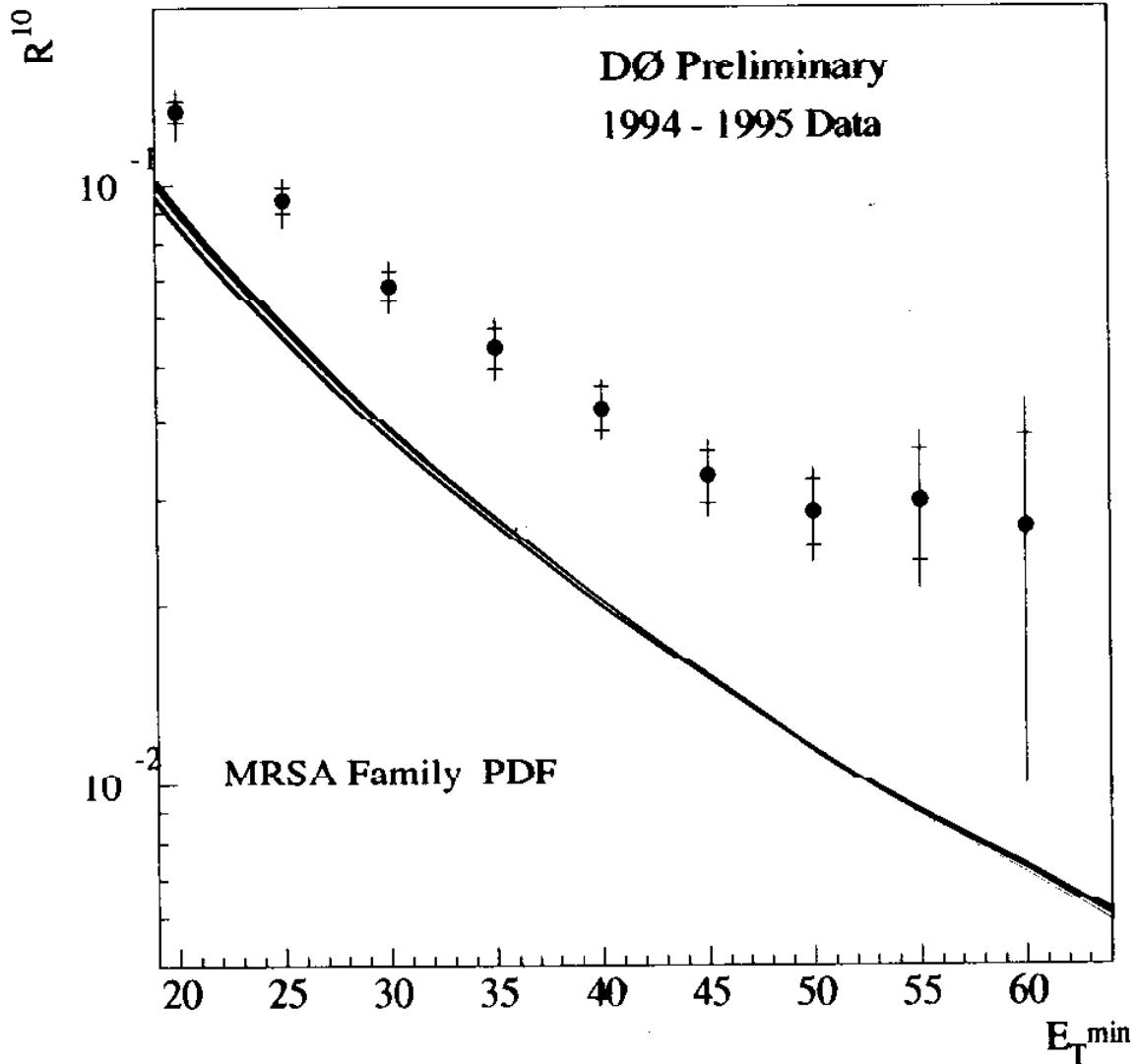
α_s and PDF's

- * Λ_{QCD} is a parameter in the fits for PDF's
- * Each PDF has one value of $\alpha_s(M_W)$ associated with it
- * Need new PDF fit to get new $\alpha_s(M_W)$
- * families of PDF's with various values of $\alpha_s(M_W)$
- * Two used here - CTEQ4 and MRSA'

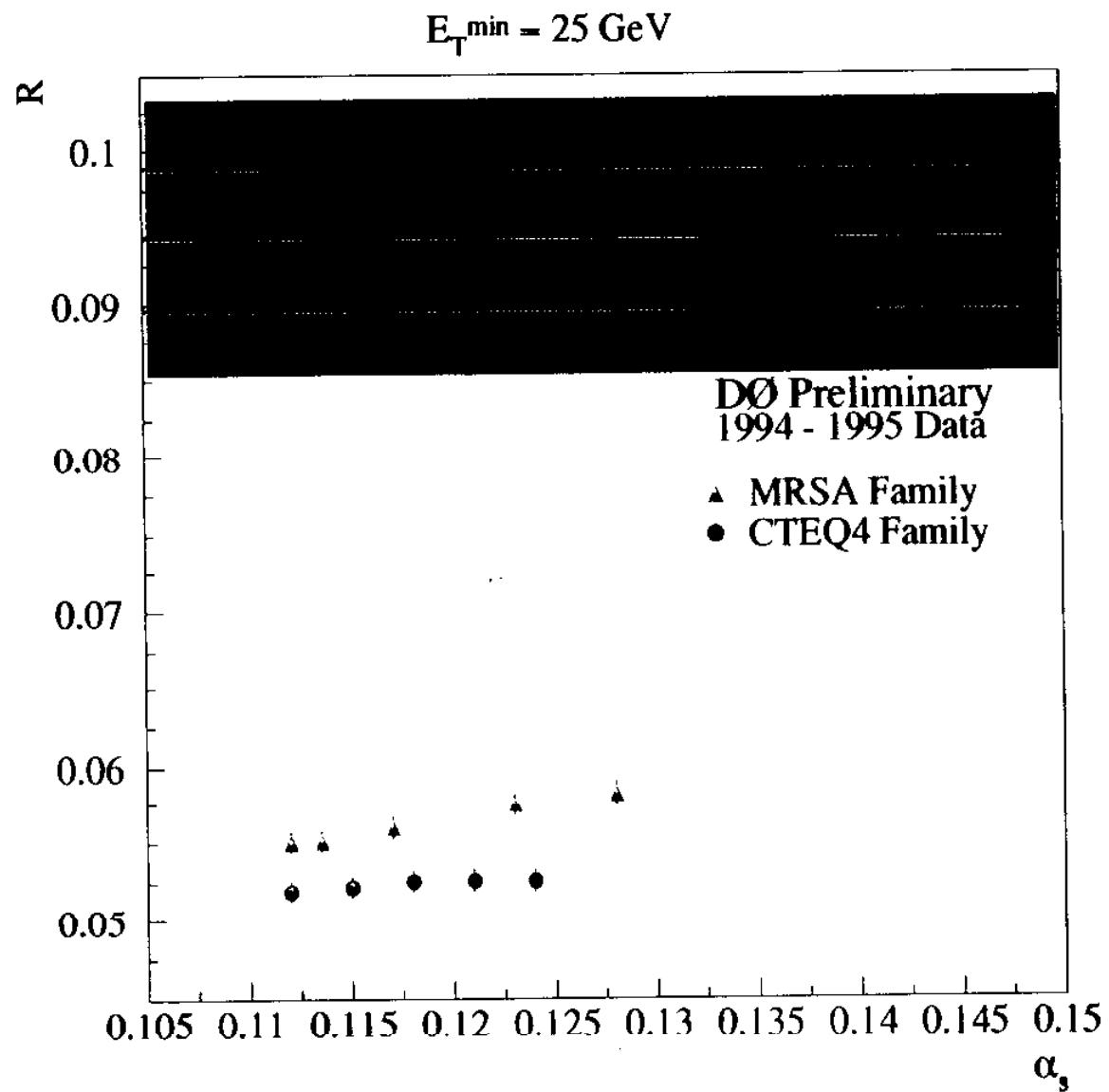
R^{10} versus E_T^{\min} with CTEQ4 Family



R^{10} versus E_T^{\min} with MRSA' Family



R^{10} versus α_s



Other Studies for R^{10}

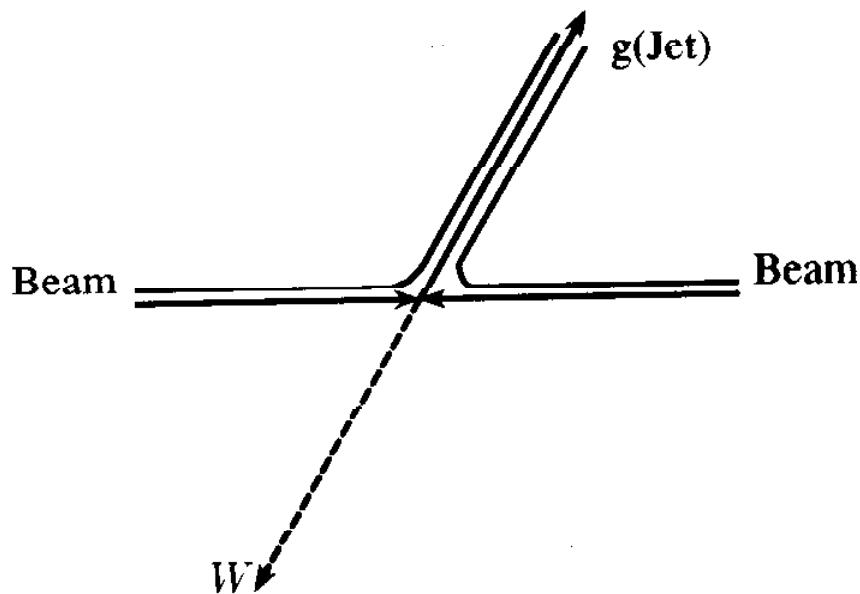
- * DYRAD does reproduce the total W cross section measured at DØ.
- * DYRAD agrees with the 630 GeV result from UA2.
- * UA2 and DØ are at different center of mass energies and therefore are sensitive to different x regions of the PDF's and different mixtures of partons in the proton.
- * DYRAD μ -scale has been varied from $M_W/2$ to $2*M_W$ with very little change in the NLO result.

Color Coherence

- * Definition - interference of the soft gluon radiation emitted between color connected partons
- * Perturbative Part - Angular Ordering
 - * outgoing partons: decrease of successive emission angles of soft gluons
 - * incoming partons: emission angles increase as process develops toward interaction
- * Non-perturbative Part - Fragmentation
 - * particle distributions influenced by color connections between partons during fragmentation

Color Coherence

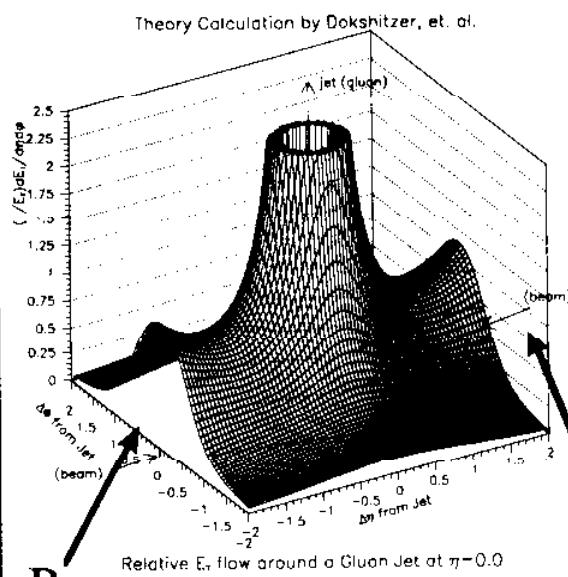
- * Use W+Jets event
- * compare pattern of soft particles around the jet and the W (colorless)
- * $W \rightarrow e\nu$ events: W does not contribute to particle production



Color Coherence Model

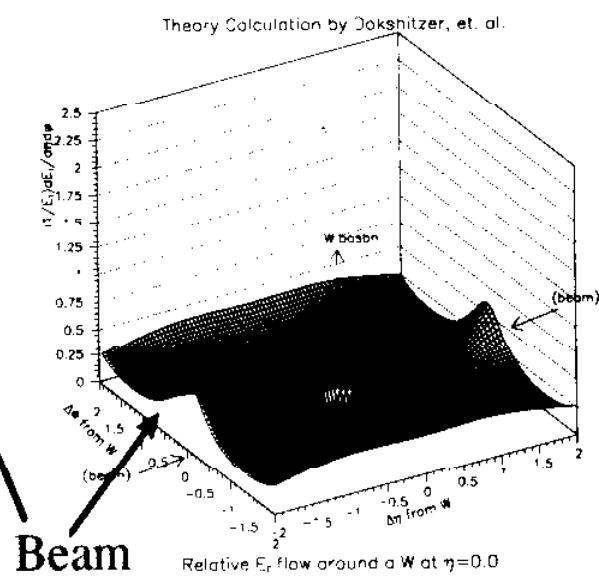
* model from Dokshitzer, et al:

Jet side:

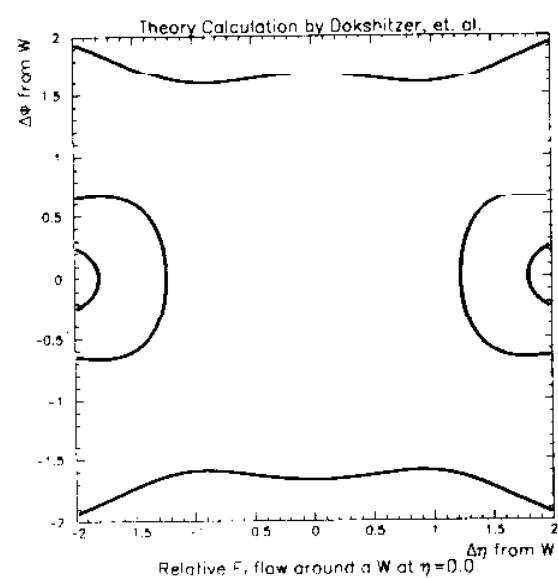
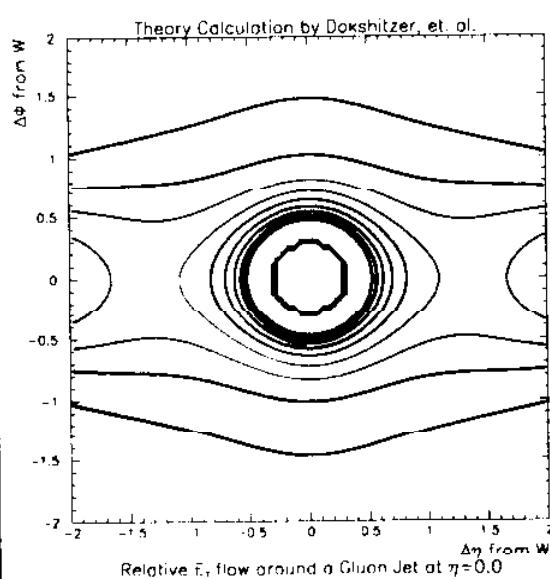


Beam

W side:



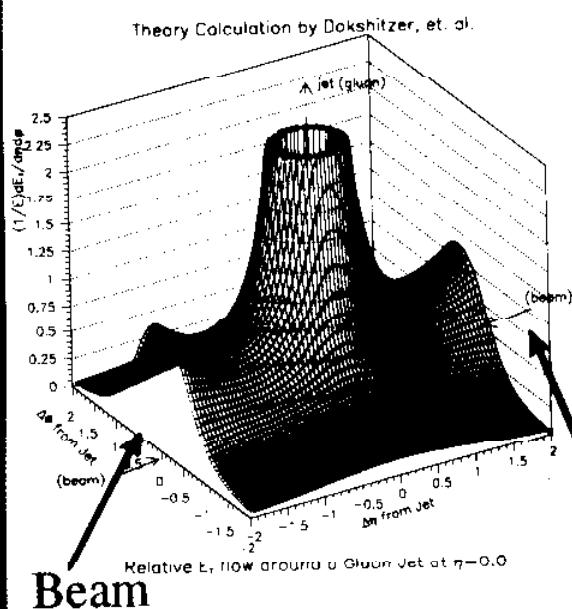
Beam



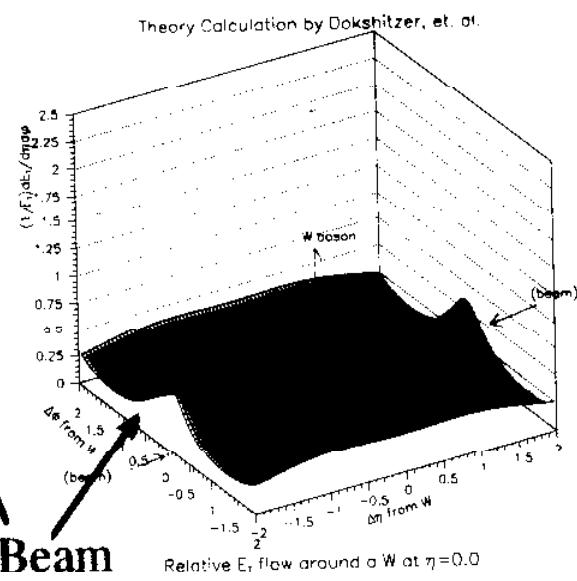
Color Coherence Model

* model from Dokshitzer, et al:

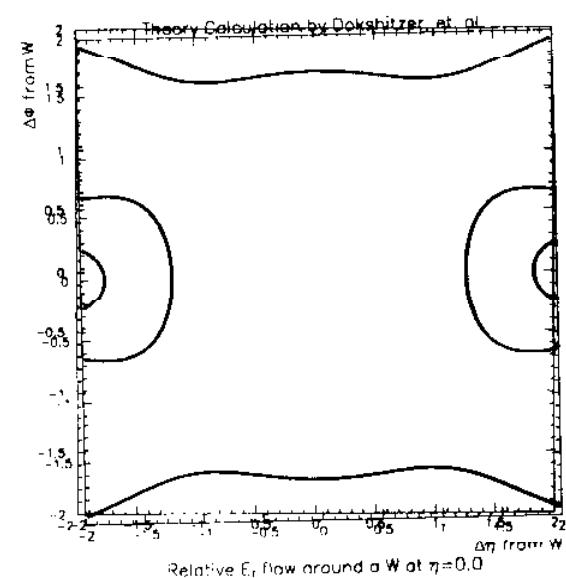
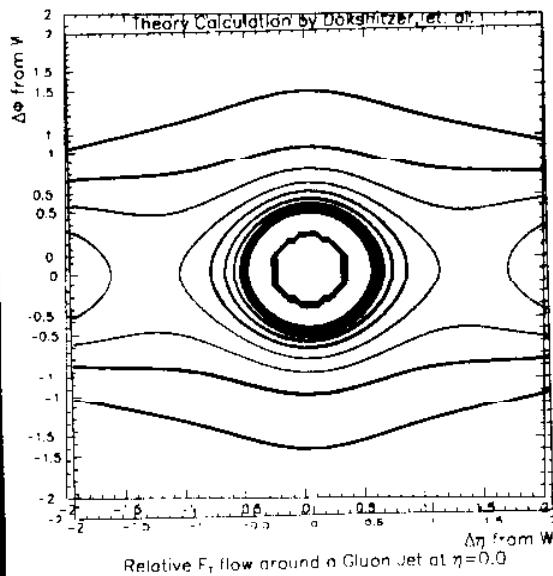
Jet side:



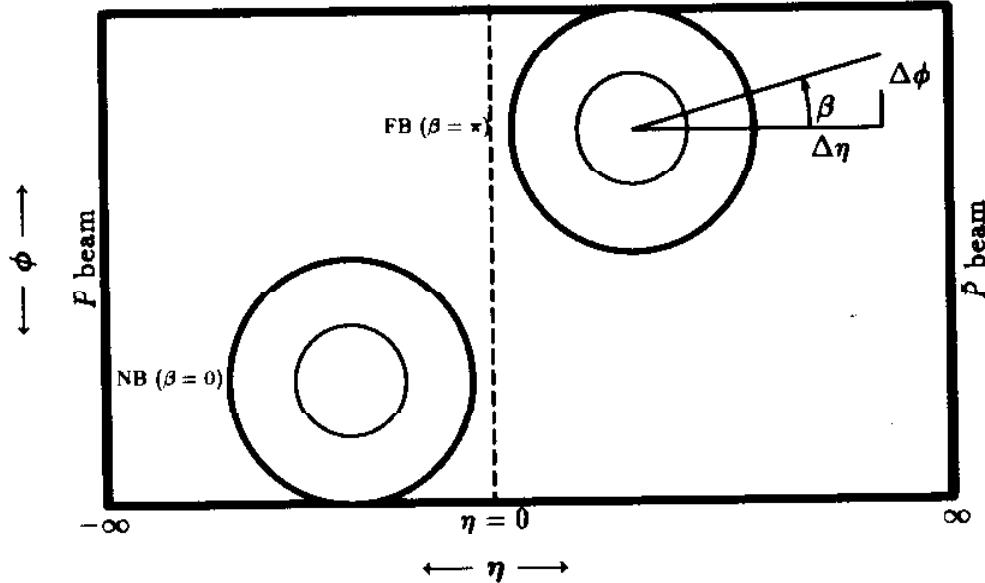
W side:



Beam



Color Coherence Method

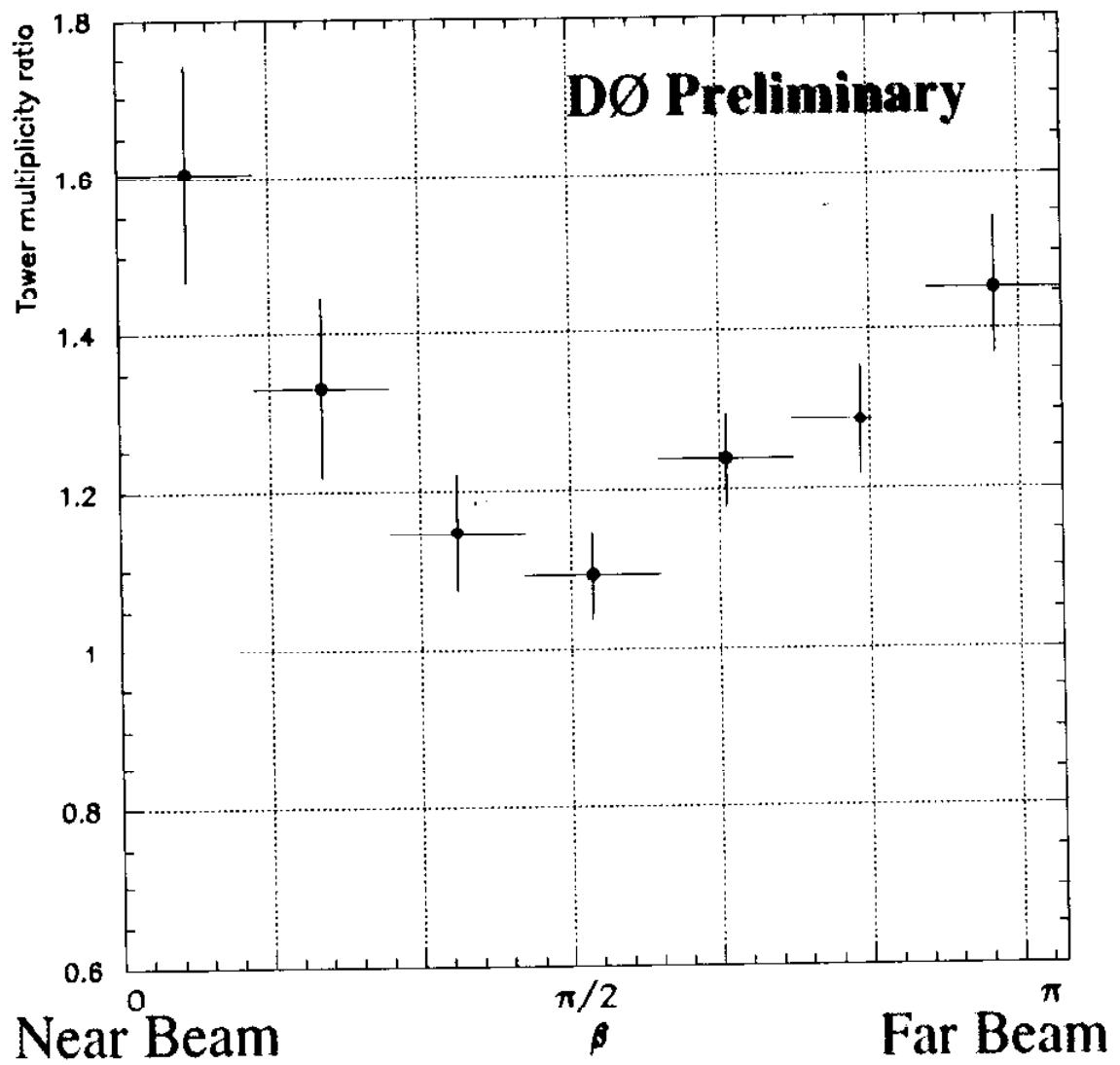


- * Count number of towers with $E_T > 250 \text{ MeV}$ in each annular region
- * plot $N_{Jet}^{Tower} / N_w^{Tower}$ versus β
 - * $\beta=0$ - “near” beam; $\beta=\pi$ - “far” beam
 - * $\beta=\arctan(\text{sign}(\eta_{W,jet}) \Delta\phi / \Delta\eta)$
 - * search disk: $R^{\text{inner}}=0.7$, $R^{\text{outer}}=1.5$
- * fold about ϕ axis to improve statistics

Data and Monte Carlo

- * Data from 1994-1995 collider run
 - * electron $E_T > 25 \text{ GeV}$
 - * missing $E_T > 25 \text{ GeV}$
 - * at least one jet ($R_{\text{cone}} = 0.7$)
 - * $E_T > 10 \text{ GeV}$
 - * loose $\Delta\phi$ cut between W and jet
($\pi/2 < \Delta\phi < 3\pi/2$)
 - * $|\eta_{\text{jet}}| < 0.7$; $|y_W| < 0.7$
- * Monte Carlo - PYTHIA v5.7
 - * full detector simulation
 - * three samples
 - * “Full Coherence” - AO and string fragmentation
 - * “Partial” - No AO and string fragmentation
 - * “No Coherence” - No AO and independent fragmentation

Multiplicity Ratio

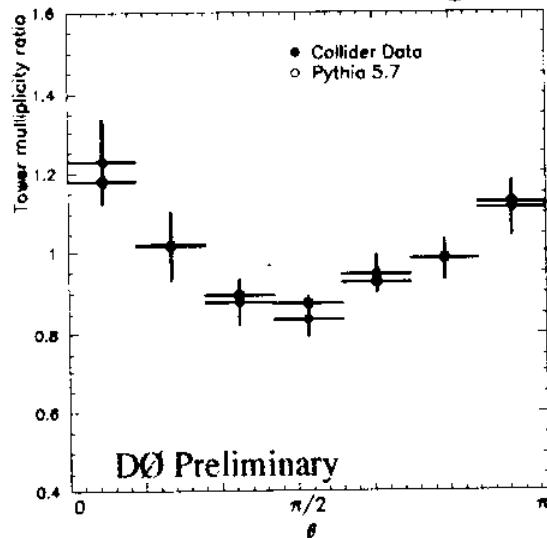


$$N_{Jet}^{Tower} / N_W^{Tower} \text{ vs. } \beta$$

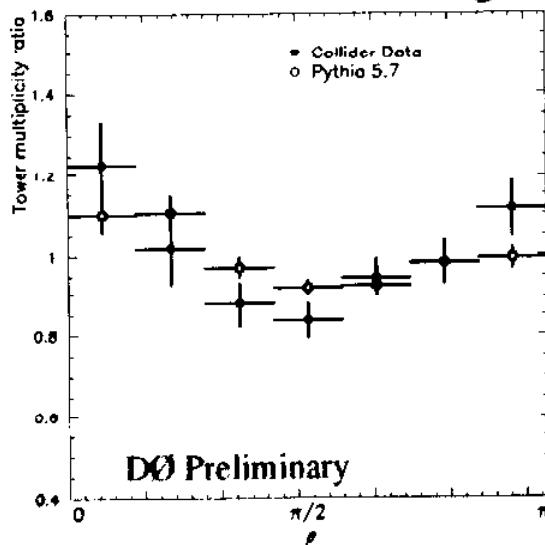
Data Compared to Pythia

- * tower multiplicity ratio versus β
- * Patterns are normalized to compare shapes

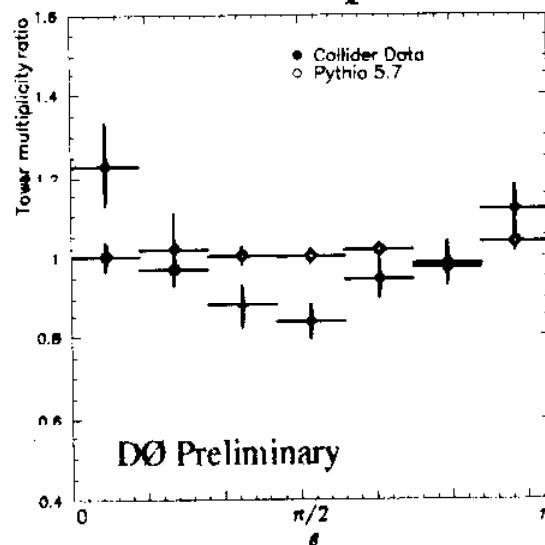
AO and string



No AO and string



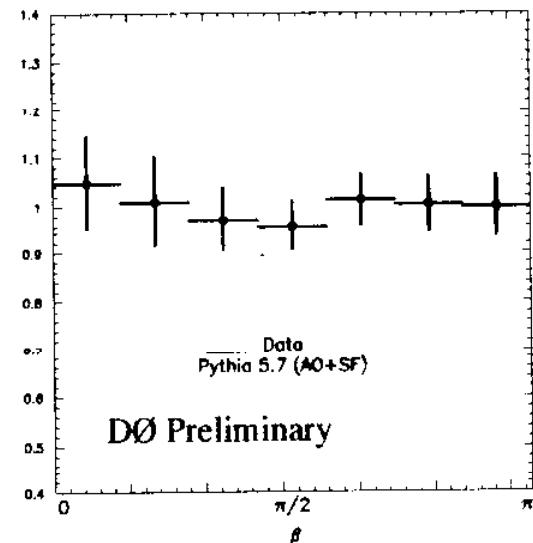
No AO and independent



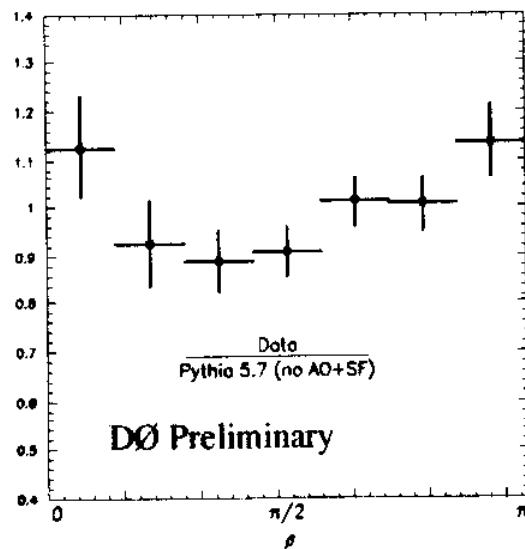
Comparisons to Theory

* data divided by
PYTHIA

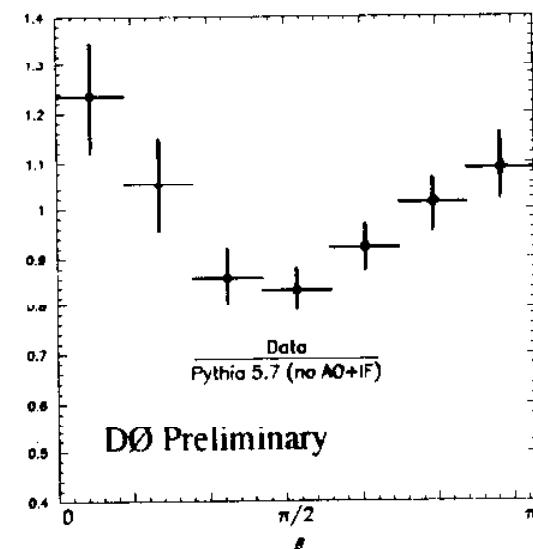
AO and string



No AO and string

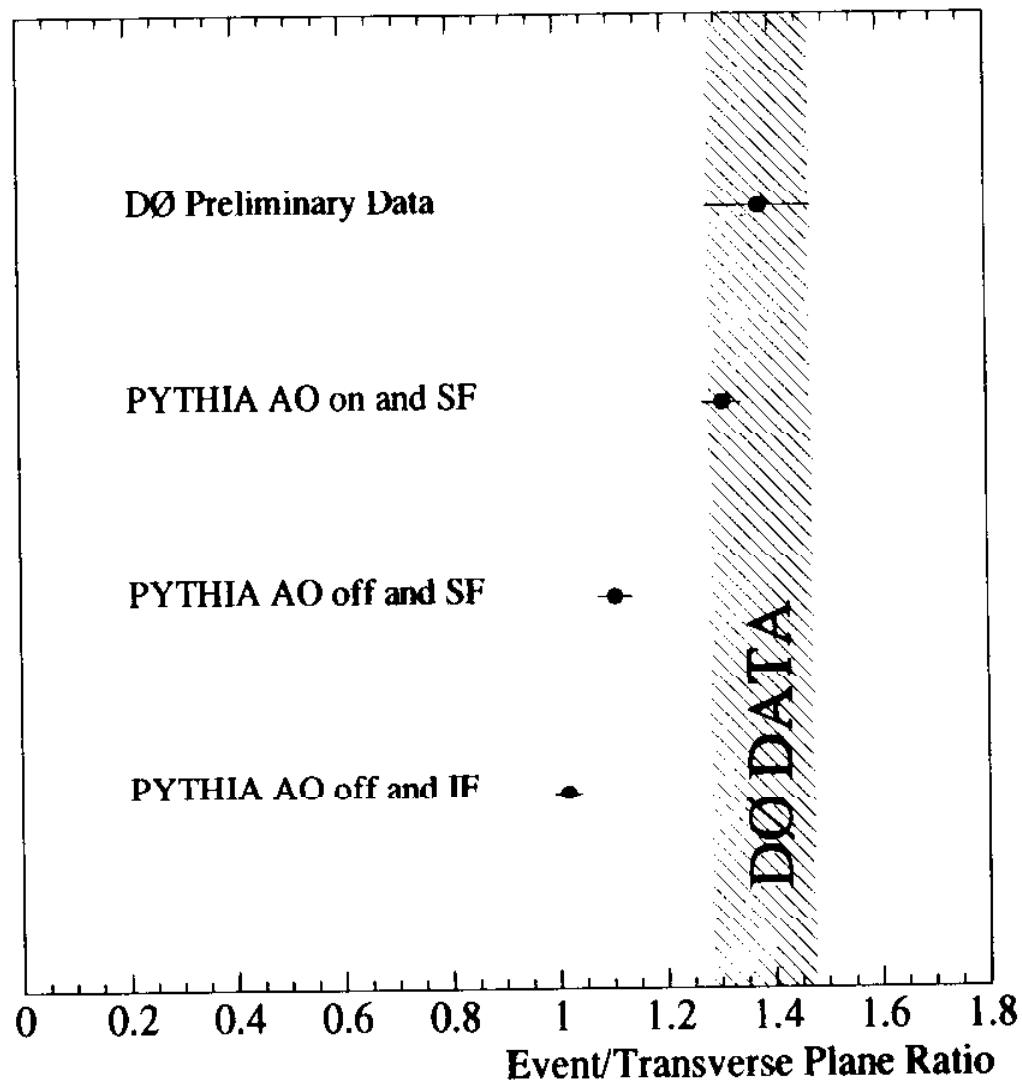


No AO and independent



Comparison to PYTHIA

W+Jet Color Coherence Result



- * average multiplicity ratio at $\beta=0$ and $\beta=\pi$
- * divide $\beta=0$ ratio by $\beta=\pi/2$ ratio

Conclusions for DØ Analyses

- * The measurement of R^{10} is higher than the NLO theory prediction by a factor of 1.8 for an E_T^{\min} of 25 GeV.
- * Color Coherence effects between initial and final states have been observed in W events at DØ.
- * Monte Carlo predictions using angular ordering with string fragmentation reproduce the pattern of soft particle production in W+Jets events as seen in data.